Integrated 2-Stage Anaerobic Digestion to Reduce Dairy GHG Emissions

7th Annual AgSTAR National Conference

Indianapolis, Indiana

June 11, 2013

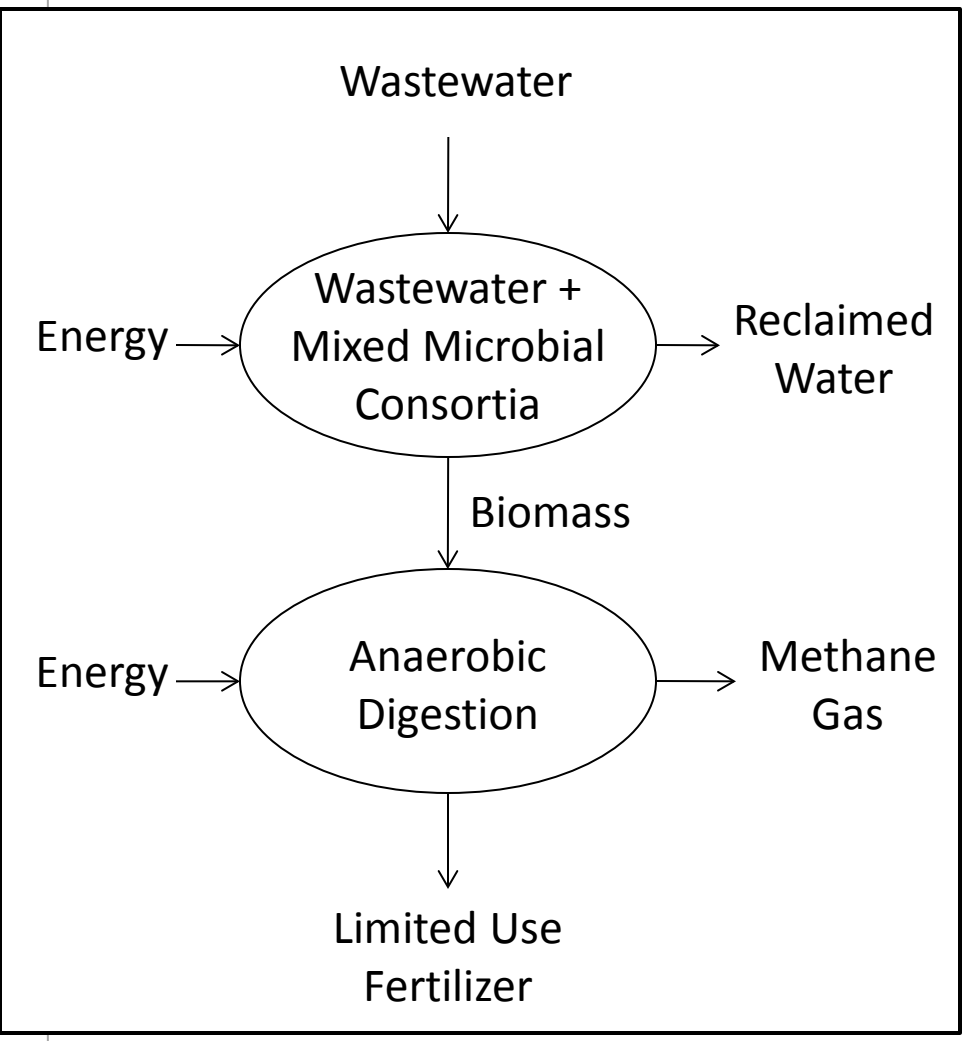
Erik R. Coats, P.E., Ph.D. - Associate Professor of Civil Engineering

Also: Kevin Feris (BSU), Maxine Prior (UI), Erin Searcy (INL)

College of Engineering

University of Idaho

Conventional Waste Management



Process is 1-D: treatment

Design by necessity to manage end products….not at a systems level to maximize resource use

Very energy intensive

Resource is significantly un/underutilized

Overview of this talk

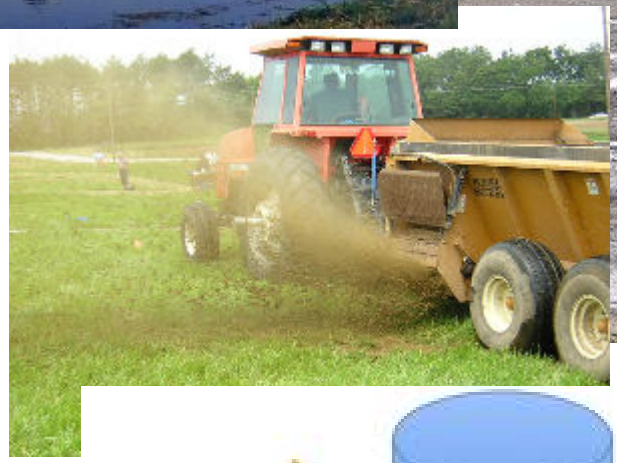
- We need to instead focus waste mgt on….
  - Resource recovery
  - Concurrently reduce emissions
  - Waste = Value = $
- Dairies have a waste management problem
- Our dairy manure research/technology….
  - Centered on 2-stage Anaerobic Digester (AD) configuration
  - Bioplastic (PHA) production
  - Integrated algae production using AD/PHA effluent

Why Dairy Waste?

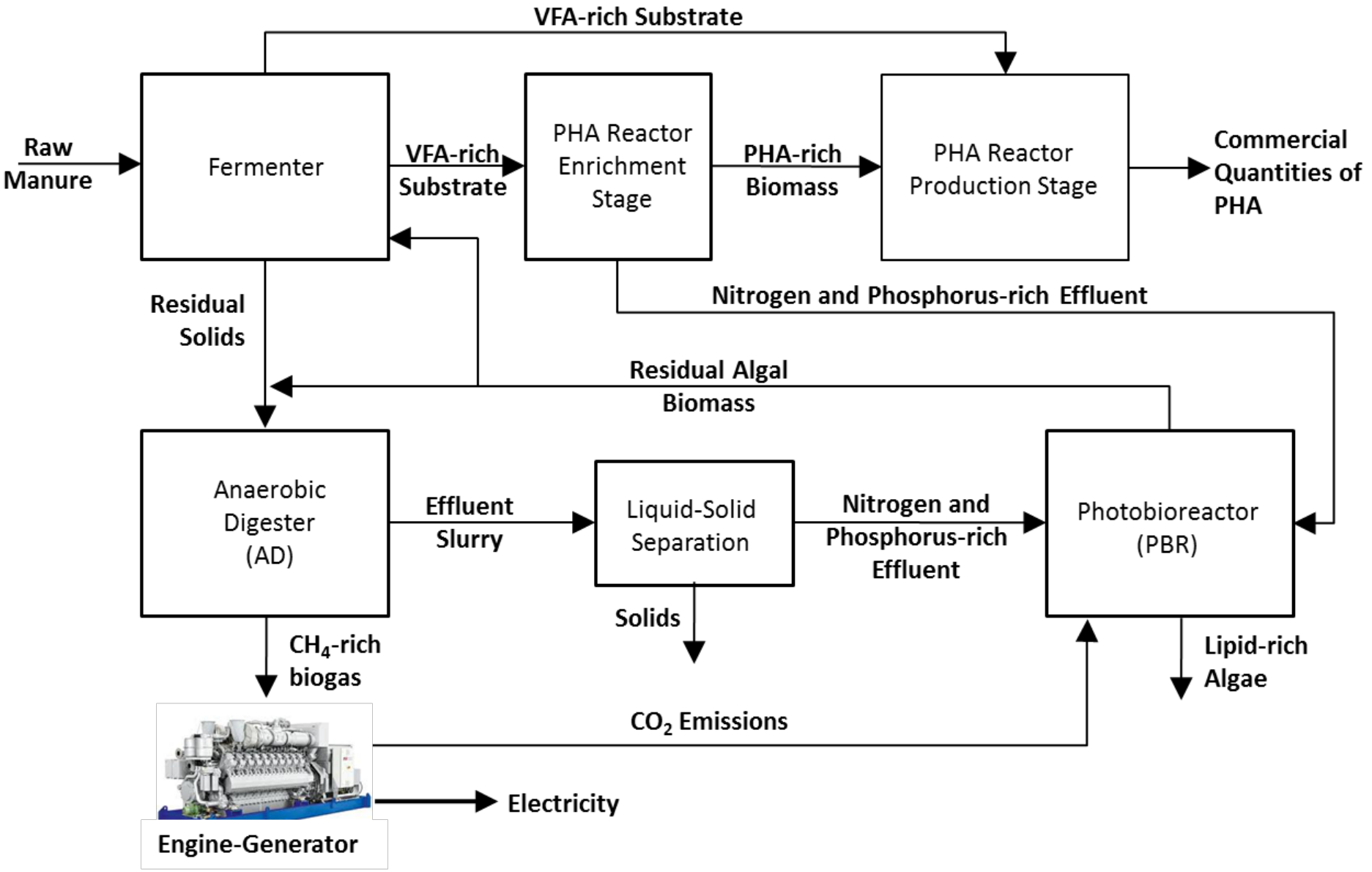
- Over 9 million dairy cows in U.S.
- Dairies = significant economic impact…in Idaho:
  - $2.5B in on-farm cash receipts in 2011……>36,000 jobs
- However, manure mgt is a growing concern
  - ~ 249 million tons/yr of wet manure in U.S.
  - ~13 lbs N and 2 lbs P per wet ton
  - GHG emissions
- Achieving sustainable agricultural practices….
  - DOE: interest as applied to biofuel production
  - USDA: nutrient management, GHG mitigation
  - Industry: enhance economics, reduce emissions

Current Manure Management Practices

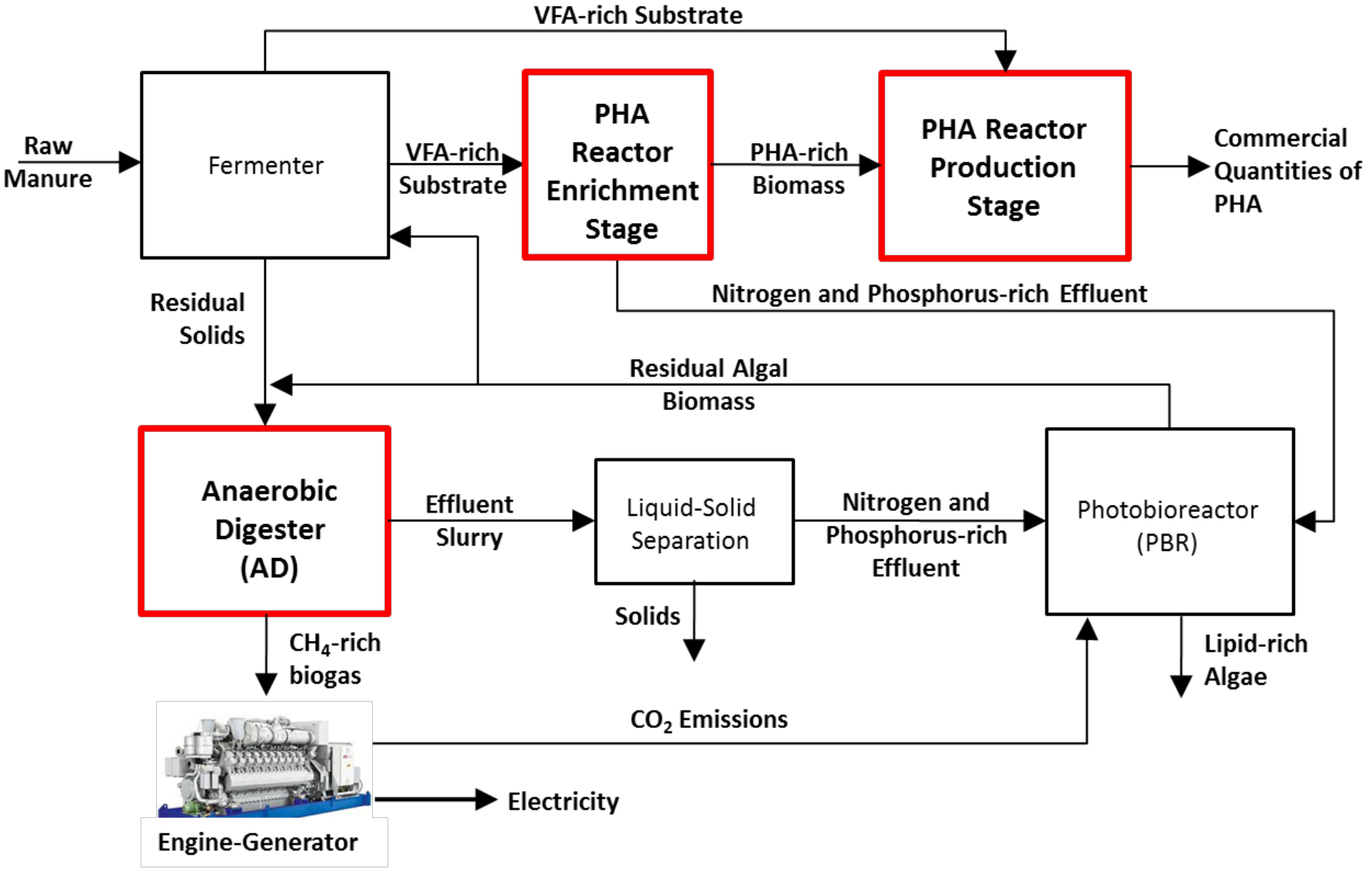
- Lagoon storage, composting, land application
- Anaerobic digestion
  - Innovation Center aggressively promoting AD
  - but economics, reliability, stability ultimately limit AD use (only 4.8% of candidate dairies employ AD (EPA AgStar, 2010))
  - Shale oil further impairs economics
- Most critically: all are treatment centric….simply a “cost of doing business”



Our Integrated Process



Focus of this talk



Bio-methane Production

Manure-to-Energy: Methane Gas

- Practiced currently at some dairies
  - Digest raw manure to produce CH_4-rich biogas
  - Gas → electricity
- Our process: digest fermented residual manure
  - Maximize extraction of value from manure
  - Prove concept, then advance the process

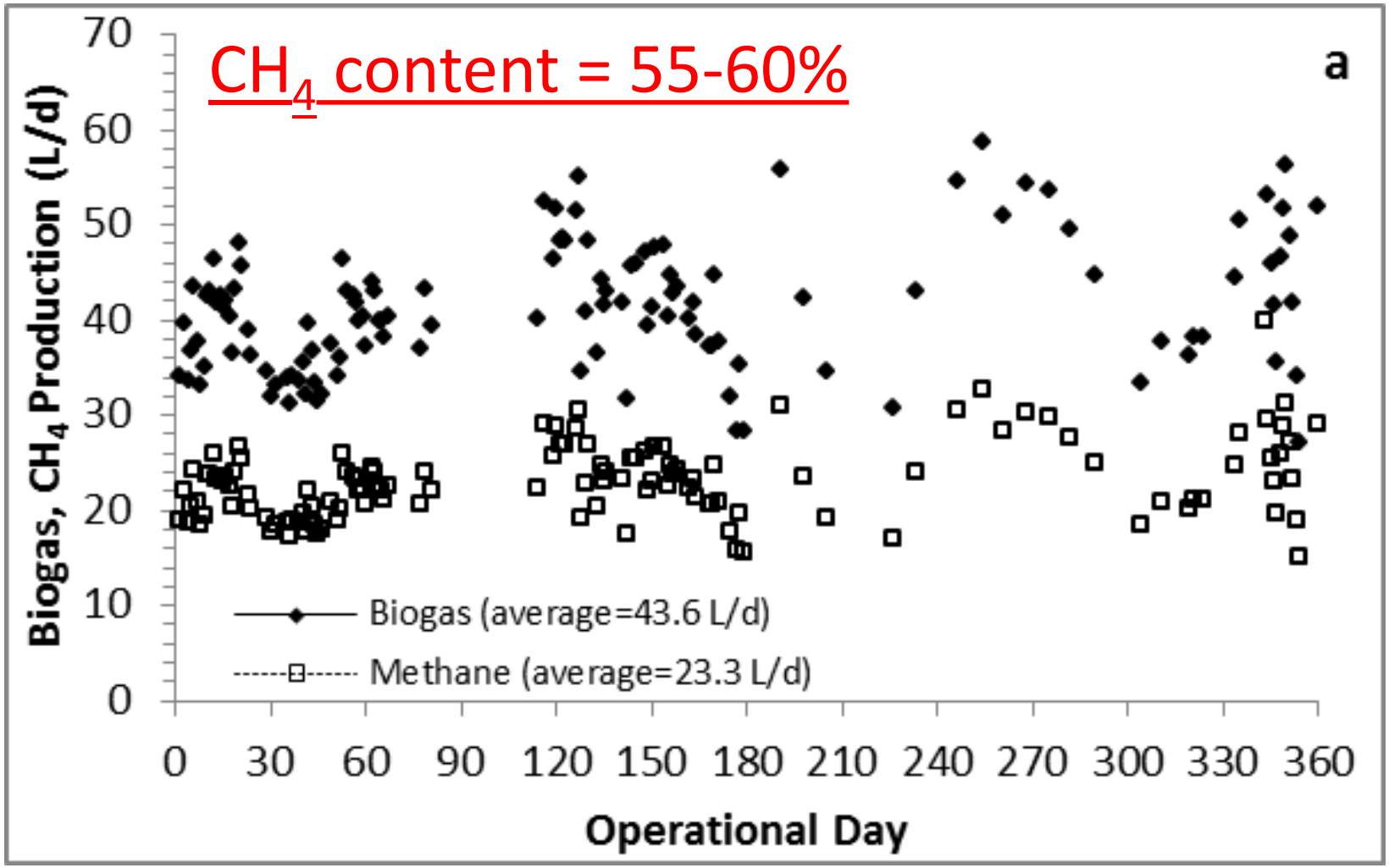
- No flaring!!

AD Performance Summary

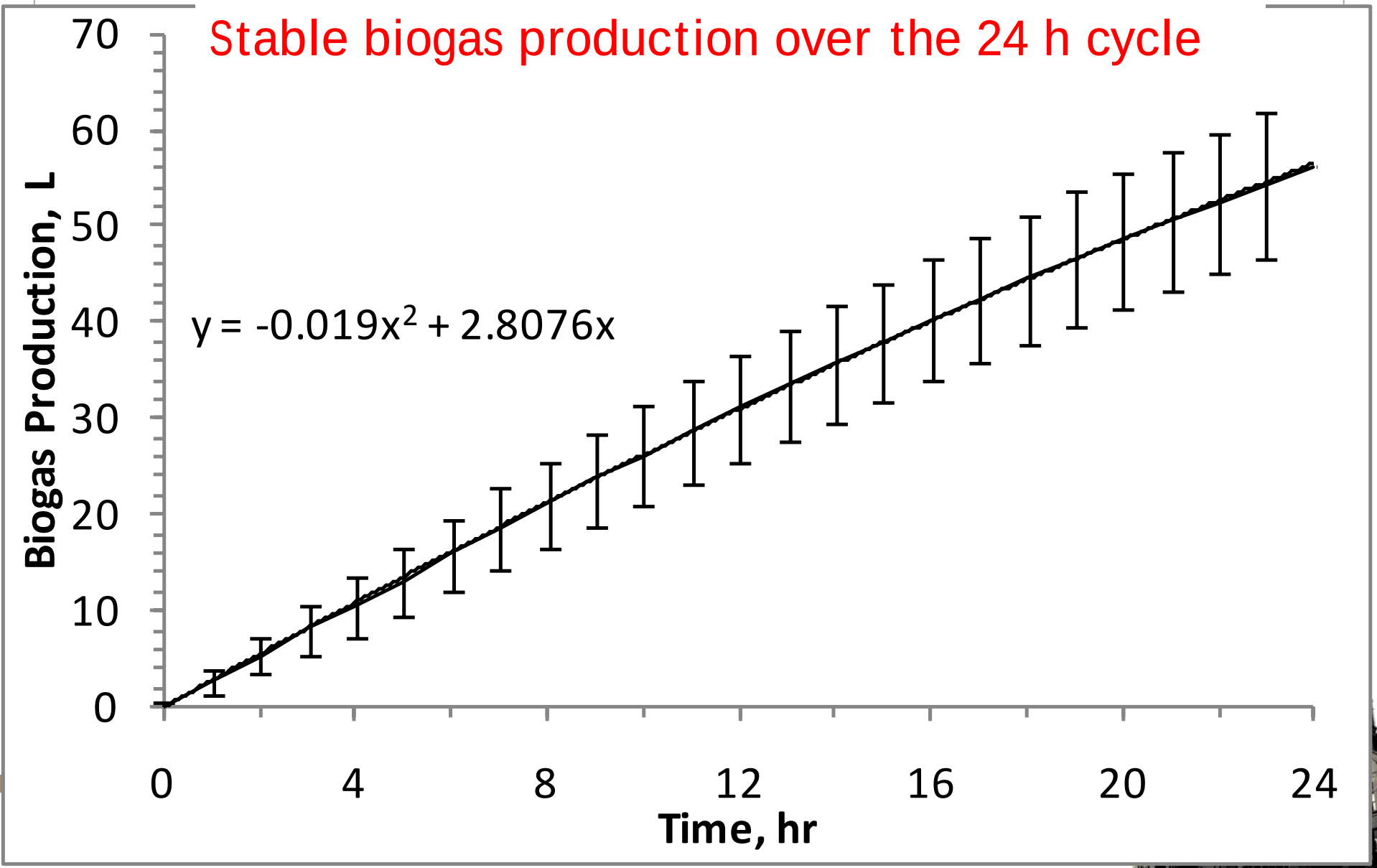
2-stage configurations

	Raw	16d SRT	20d SRT	30d SRT
OLRs (gVS/L-d)	3.7	4.2	3.36	3.09
OLRs (VS + VFAs; gC/L-d)	1.88	2.31	1.84	1.67
L biogas/gVS destroyed	0.84	0.76	0.87	0.85
L CH_4/gVS destroyed	0.43	0.41	0.49	0.46
L biogas/gVS applied	0.37	0.31	0.30	0.34
L CH_4/gVS applied	0.19	0.17	0.17	0.19
L biogas/L-d	1.36	1.3	1.02	1.07
L CH_4/L-d	0.70	0.71	0.57	0.58

Stable Biogas Production



Biogas Production over a Cycle



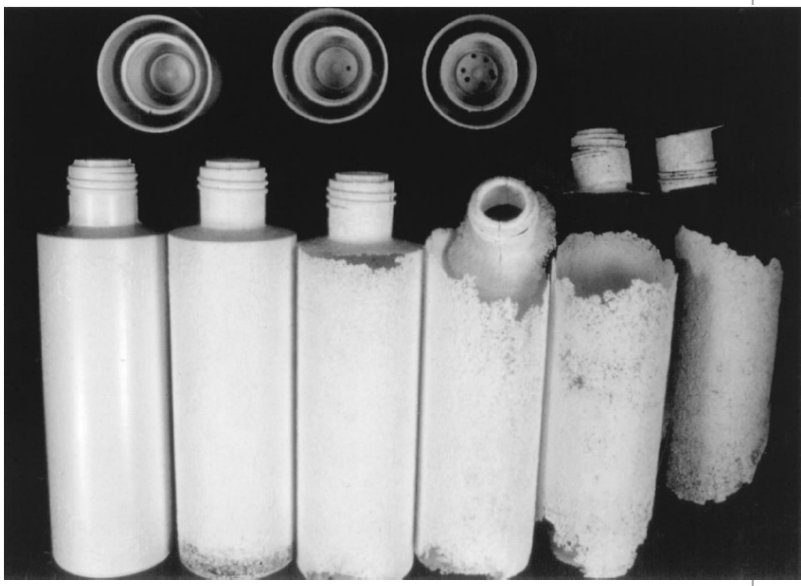
Process Stability & Resiliency

- Statistically comparable CH_4 content in the biogas
- Stable performance: over > 2 yrs without upsets
- Methanogens dominated by methanosarcina
  - ~ 4X the methanogens in 2-stage (vs. single stage)
- 2-stage AD more enriched with fiber-degrading fermenting bacteria
- Fermentation yields two distinct solids streams
  - Lignocellulosic-rich fraction
  - Potentially lipid-rich fraction
  - Separate stage AD may further enhance biogas yields….ongoing investigations will confirm

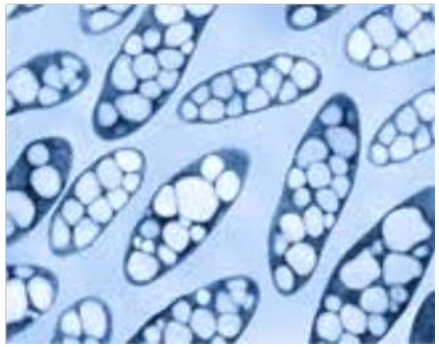
PHA Production

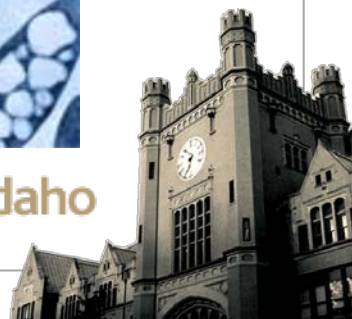
What are Polyhydroxyalkanoates (PHAs)?

- Bacterial carbon and energy reserves
- Bacterial-derived polyesters
- Biodegradable thermoplastic when extracted from the microbial cell
- Synthesized by microbes under stress conditions
- PHA form = f(carbon source)
  - Material properties vary with co-polymerization

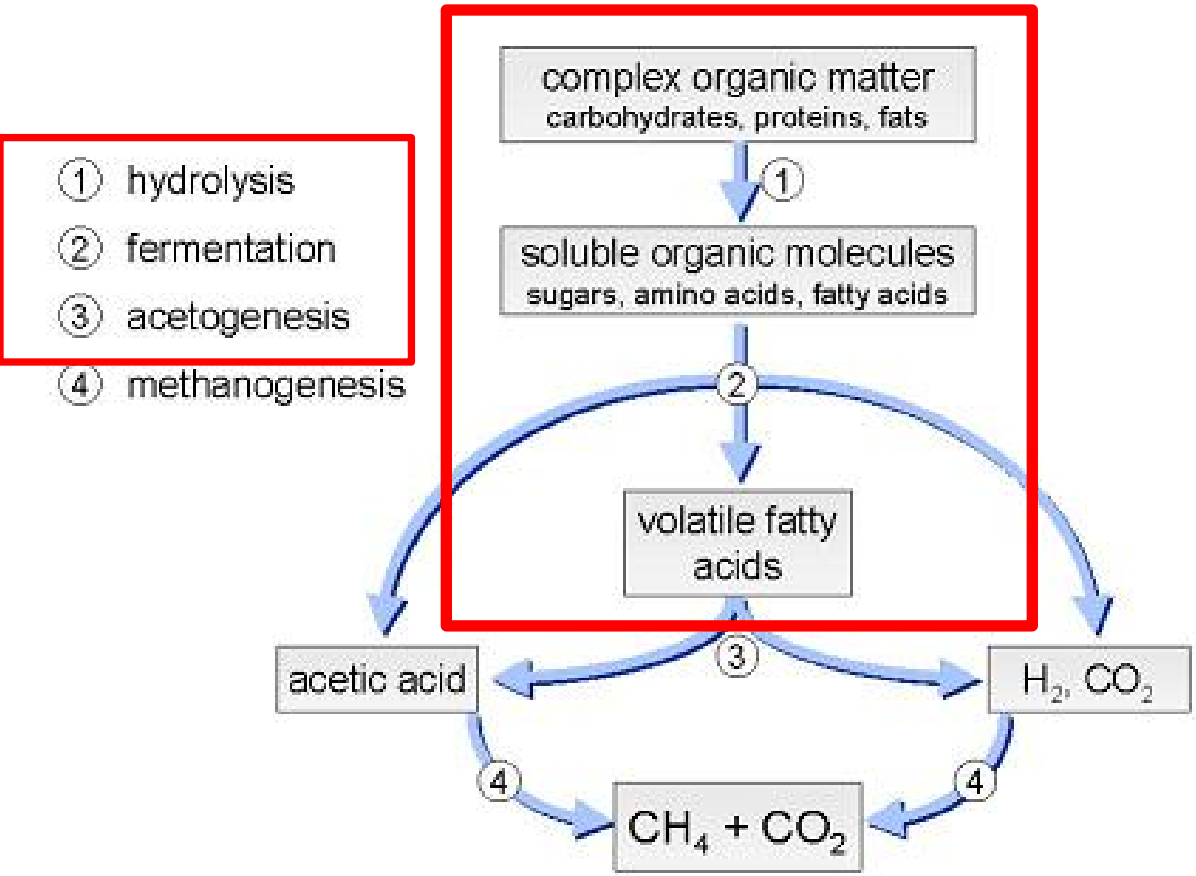


Degradation of PHBV bottles in aerobic sewage sludge after 0, 2, 4, 6, 8, and 10 weeks shown from left to right.





Our PHA Process Requires Organic Acids



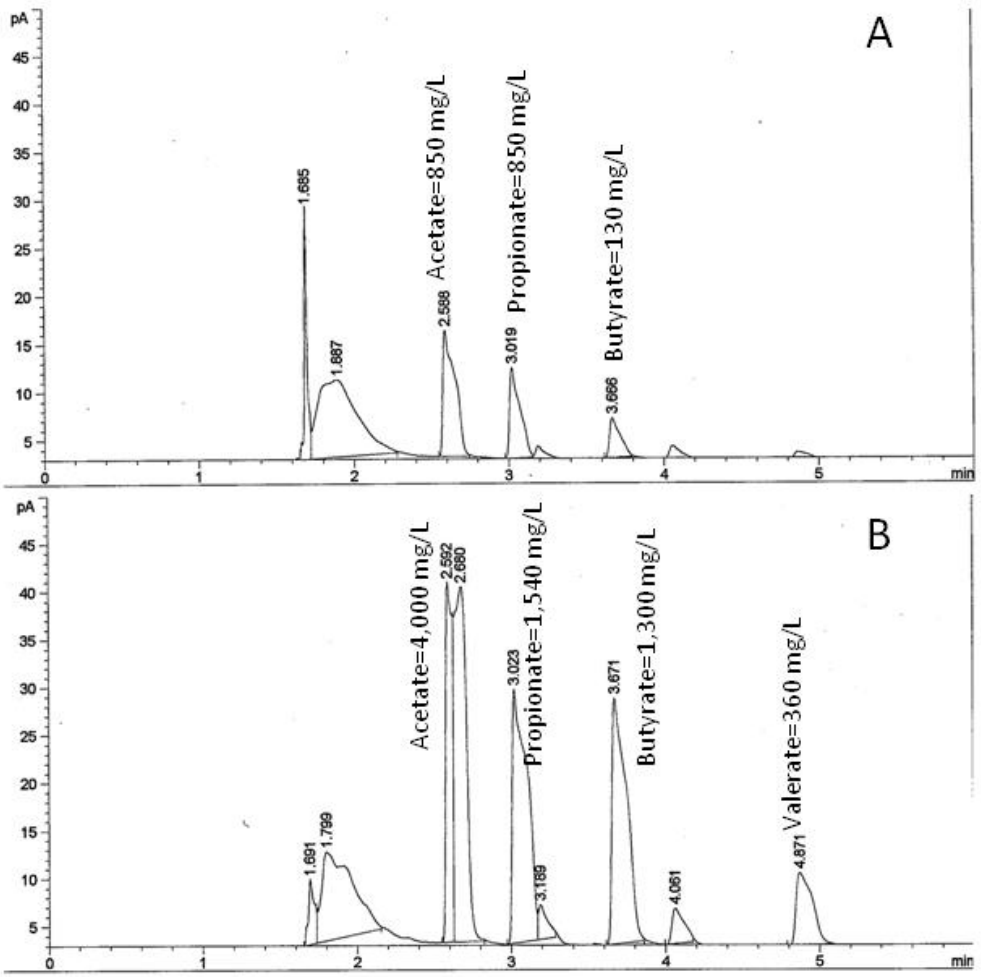
Dairy Manure Fermenter

Dairy Manure 'Production' Fermenter

Significant volatile fatty acid (VFA) yield

- Acetic (3,200-3,300 mg/L)
- Propionic (1,360-1,500 mg/L)
- Butyric (750-2,200 mg/L)
- Pentanoic (300-1,100 mg/L)
- Estimate > 1,000 lb VFA/d from 2,000 head dairy
- Ongoing research to optimize

Excellent precursors for PHA synthesis

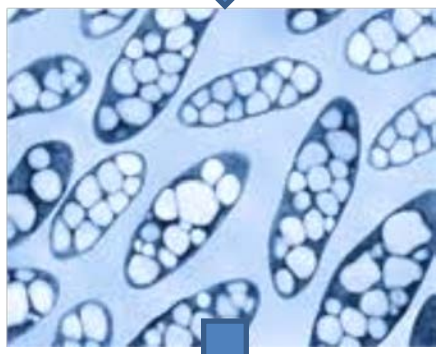


Chromatograms showing respective VFA forms and yields from two contrasting dairy manure fermenters: (A) SRT=2 days; OLR=7, and (B) SRT=4 days, OLR=15. See also Table 1.

PHA on Dairy Manure

Induce feast/famine PHA synthesis: characterized by.....

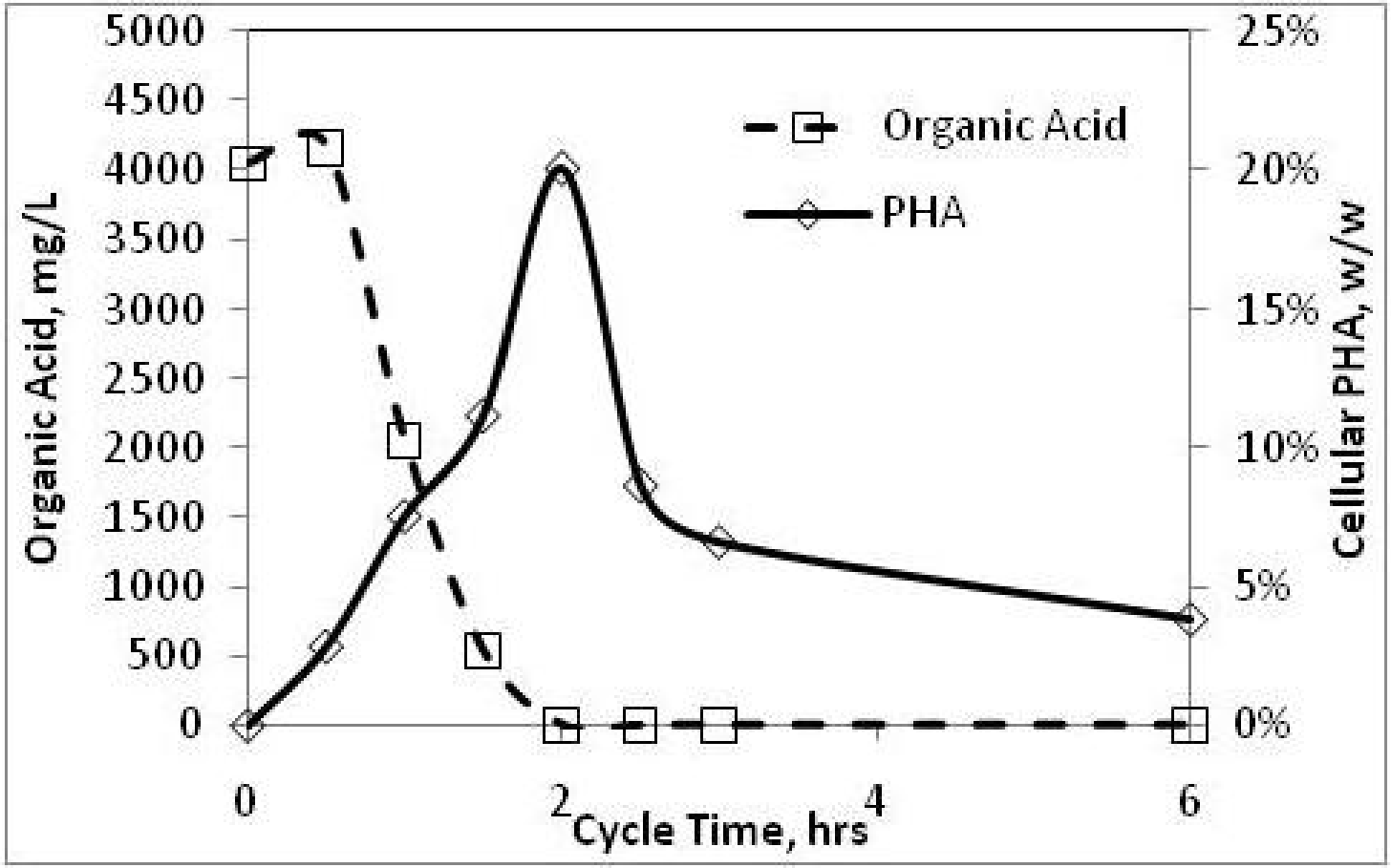
- High initial concentration of organic carbon (feast)
- Ultimate depletion of organic carbon + nutrients (famine)



Coats' lab-example bioreactor installation

"Enrichment" PHA Reactor

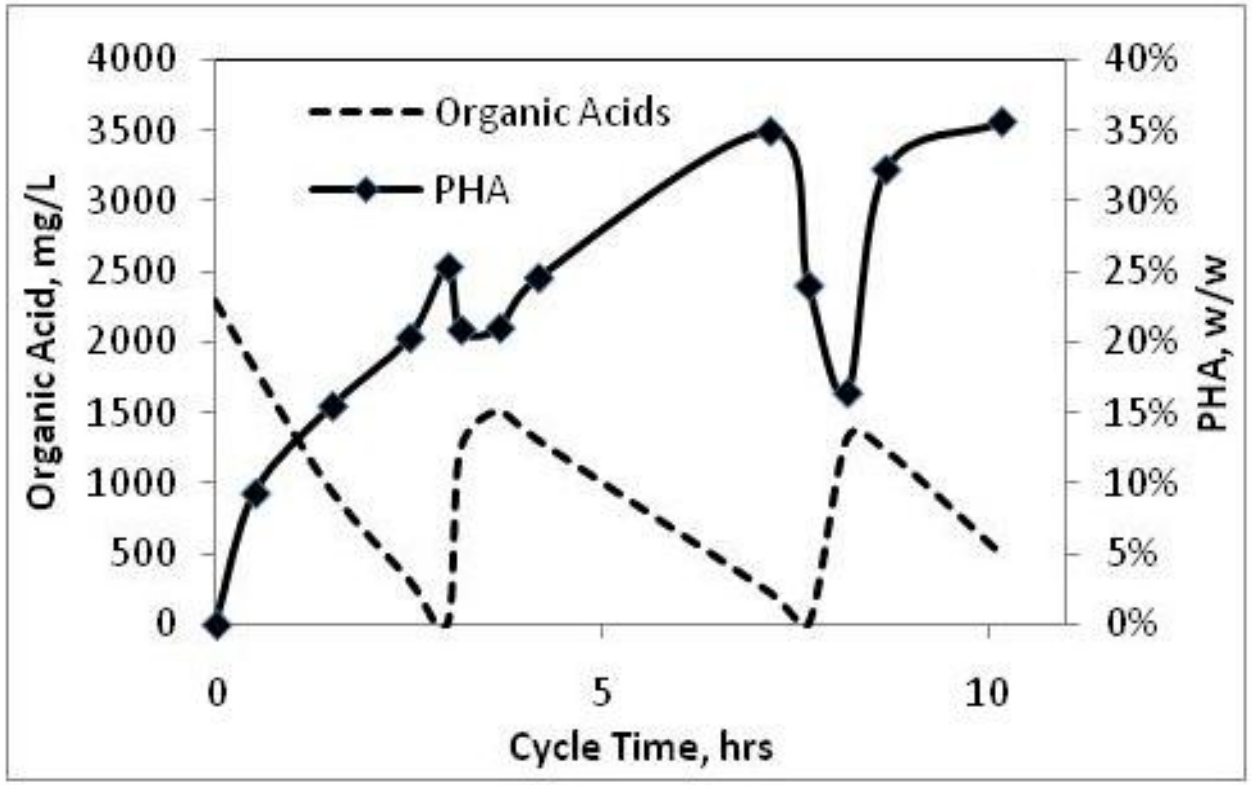
- Enrich for bacteria capable of feast/famine PHA synthesis



Feast-Famine PHA Synthesis in a 1st Stage Bioreactor

“Production” PHA Bioreactor

- Generate commercial quantities of PHA
- Biomass = 70% PHA (weight basis)
- Current manure-to-PHA yields commercially viable – ongoing research to optimize



PHA Synthesis in a 2nd Stage Bioreactor (Step Fed Organic Acids)

University of Idaho

PHA Applications

- Biomedical
  - Drug delivery: time release capsules
  - PHA-based nanoparticles for cancer treatment
  - Eyelid reconstruction using PHA-base scaffolds
- Industrial
  - Convert to biofuels
  - Latex for surface coating paper
  - Packaging (use PHB-co-HV, not PHB (too brittle))
- Aquaculture/Agriculture applications
  - Mixed with fish food, may convey some antibacterial effects
  - Controlled release of herbicides, pesticides

PHA-rich Biomass Composites

Extruded using un-extracted PHA

- Cellular PHA + residual microbial biomass

Wood-plastic composites

	PP	Carbomer – PHB	PHB-Rich Biomass	
			43% PHB	32% PHB
Density (kg/m^3)	1003	1194	1280	1306
MOE (Gpa)	3.1	3.2	4.2	3.4
MOR (MPa)	44.1	30.6	25.9	20.7
Strain at Brk.	0.030	0.018	0.008	0.007

Manure-to-Plastic….Economics

- Preliminary analysis
  - $0.25-$0.50 per cow per day net profit (a very conservative estimate)
    - 2,000 head dairy
    - > 100 ton PHA per year
  - Ongoing research to increase this profit margin
- Important next-step → larger scale demonstration
  - Mobile pilot unit under construction
    - Idaho SBOE “gap” funding

Acknowledgements

- Jerry Bingold - Innovation Center for U.S. Dairy
- Bob Joblin – Cenergy USA
- Jay Kesting - Western States Equipment Co.
- Bob Naerebout - Idaho Dairymen's Association
- Center for Advanced Energy Studies, Idaho National Laboratory
  - Steve Aumeier, Ray Grosshans, Erin Searcy
- Funding: USDA, CAES/INL, NSF, Idaho Dairymen

Questions and Discussion